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Original Research Article

Comparison of Methods to Evaluate Changes in Relative Body Mass Index in Pediatric Weight Control

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ABSTRACT Our objective was to compare three BMI-based adiposity measures to assess change in pediatric weight control: LMS *z*-BMI, BMI sympercent, and percent overBMI. Comparison 1 presents changes of +1.0, −1.0, and −2.0 BMI units for 36 hypothetical children (7-, 11-, and 15-year-old children with BMI values from 19–39 kg/m^2). Comparison 2 presents effect sizes over 12 months and the relationship between baseline and change for 140 8–12-year-old children with BMI values ranging from 21 to 37 kg/m^2. Comparison 1 showed smaller changes in *z*-BMI than BMI sympercent or percent overBMI for equal changes in BMI when initial BMI values are greater. Comparison 2 showed similar effect sizes for the three measures, since there is a reduction in both standard deviation and magnitude of LMS *z*-BMI values as the BMI values increase. The three measures perform differently when considering the relationship of initial value to change. Initial percent overBMI shows a negative relationship with change, as heavier children show larger changes, LMS *z*-BMI shows a positive relationship, as children with lower baseline values show larger changes, and BMI sympercent changes were inconsistently related to baseline BMI sympercent values. Although all three measures result in similar effect sizes when evaluating treatment over time, we conclude that LMS *z*-BMI is less appropriate for comparing individuals and percent overBMI is the only measure that shows heavier children have greater change. Am. J. Hum. Biol. 19:487–494, 2007. © 2007 Wiley-Liss, Inc.

Normative data and growth charts are commonly used to convert height and weight to body mass index (BMI = kg/m^2) to classify at risk for overweight and overweight in children and to determine who may need intervention (Cole et al., 2000; Hammer et al., 1991; Kuczmarski et al., 2002; Must et al., 1991; Rosner et al., 1998). Assessing BMI over time allows the tracking of development and detection of abnormalities in growth patterns (Cole et al., 2000). An extension of the classification of childhood obesity is the measurement of treatment for obesity.

Measures of BMI change should be sensitive to treatment effects across a broad range of values, and standardized for boys and girls of different ages (Streiner and Norman, 2003). Neither weight nor absolute BMI are useful as measures of change for weight control in children. Weight is an inadequate index of either growth or adiposity as healthy weight and weight change depend on child height: taller participants should weigh more. BMI calculates weight in relationship to height, and is a good surrogate of adiposity for clinical obesity research (Dietz and Robinson, 1998; Freedman et al., 2004). However, absolute BMI is not a good indicator of obesity treatment response during growth. BMI is not linear across ages, but rather follows a well documented pattern of increase until about age 2, decrease from 2 to about age 5–7, and then a nonlinear increase until adulthood (Freedman

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et al., 2001; Rolland-Cachera et al., 1984; Whitaker et al., 1998).

An alternative to absolute BMI is to use an index of BMI which takes age and gender into account. The ideal would be to use comprehensive norms based on longitudinal data, but there are very limited examples of growth charts based on longitudinal data (Tanner et al., 1966). In the absence of longitudinal data sets, cross-sectional BMI charts (Cole, 1994; NHLBI Obesity Education Initiative Expert Panel, 1998) have been used to establish clinical definitions of overweight for children and adolescents. BMI values are positively skewed, with a narrow distribution below the 50th percentile, and a very wide distribution above the 50th percentile. One measure of relative BMI, the LMS method, converts the BMI values to normally distributed standard deviation or z-scores (Cole, 1989, 1990; Cole et al., 2000). The LMS method z-BMI scores follow the contours of BMI percentiles. LMS method z-BMI values of 0 correspond to a score at the 50th percentile, $+1.0$ corresponds to the 85th percentile, and $+2.0$ corresponds to the 97th percentile. LMS z-BMIs are interchangeable with BMI percentiles. BMI percentiles or LMS z-BMIs are useful when identifying where an individual is relative to the population norms, and may help identify those needing interventions (Kuczmarski et al., 2002). LMS z-BMI values are recommended for use in classification and assessing need for intervention.

Cole and colleagues discussed a potential problem with the LMS z-BMI measure (Cole et al., 2005). The LMS z-BMI measure attenuates change for heavier children, and the variability of the LMS z-BMI values are significantly inversely related to the baseline z-score. Thus, as children become more overweight, they will show less change and the variability in their response to treatment is reduced (Cole et al., 2005). This may be a problem in comparing treatment effects for children who differ in their initial BMI. For example, if a group of children show similar changes in BMI, the heavier children will show smaller reductions in LMS z-BMI values due to the attenuation in response.

A second measure of relative BMI is BMI sympercent (Cole et al., 2005). Cole developed sympercents (Cole, 2000) which remove the attenuation in values as the values become greater and remove the influence of baseline values on variability. The sympercent is the percent difference from the age and gender appropriate 50th percentile BMI value based on the natural log scale.

A third measure that is often used to assess change in pediatric weight control programs is percent overBMI. Percent overBMI is the percentage above the 50th percentile BMI for the appropriate age and gender. Prior to the common use of BMI as a measure of overweight, the percentage over the average weight for youth at different ages and heights was calculated as the percent overweight (Jelliffe, 1966). As BMI rather than weight for height was used more frequently, investigators calculated percent overweight in reference to the 50th percentile BMI. Percent overBMI provides a value relative to the 50th percentile, where positive values are over the 50th percentile and negative values are under the 50th percentile.

The purpose of this paper is to compare child relative weight change using hypothetical and measured LMS method z-BMI, BMI sympercent, and percent overBMI data for children. The paper extends Cole's research on the attenuation of response for LMS z-BMI and the inverse relationship between baseline values and variability (Cole, 2000; Cole et al., 2005) for a wider age distribution, and includes percent overBMI in the comparison of measures. In addition to studying differences in the magnitude of change, and the relationship between baseline values and variability, two additional characteristics of the measures were studied. First, the measures were compared in terms of effect size, which relates the magnitude of change to variability. It is not clear how effect size is altered when there is attenuation in magnitude of change which is accompanied by reduction in variability of change over time. Second, the relationship between baseline values and change was studied. Many dependent measures show a significant relationship between baseline values and change, as those with greater values show greater change. This is called the law of initial values (Wilder, 1967), and research has shown that greater initial percent overweight in children is inversely related to more success in a weight control program (Epstein et al., 1994).

These characteristics of the three measures were studied in two comparisons. Comparison 1 illustrates how initial degree of adiposity relates to the magnitude of changes in each measure of relative BMI. Three hypothetical changes representing reasonable increases and decreases in BMI that could occur over a 1-year period were used to illustrate differences in how each relative BMI measure reflect the magnitude of changes for children who differ in their initial relative BMI values. Age, gender, and BMI changes were kept constant in each comparison to ensure that differences illustrated were a result of the method employed to compute relative BMI.

Comparison 2 used 6- and 12-month change data from 8–12-year-old children from pediatric weight control studies to examine differences in magnitude, variability, effect size, and the relationship between baseline values and change for each relative BMI index.

METHODS

Relative BMI measures

The formula for calculating LMS z-BMI scores based on age and sex is LMS method z-BMI = ((BMI/M^L) – 1))/($L \times S$), where BMI = an individuals BMI, M = the median BMI for age and gender, L = power in the Box-Cox transformation for age and gender, and S = standard deviation for age and gender (Kuczmarski et al., 2002). BMI sympercent is calculated by the formula BMI sympercent = 100 × natural log(BMI/BMI at 50th percentile) (Cole, 2000). Finally, percent overweight or percent overBMI is calculated as %OverBMI = [(BMI – BMI at 50th percentile)/BMI at 50th percentile] × 100.

COMPARISON 1

Methods and analytic plan

To provide comparisons over a wide range of boys and girls, separate comparisons were computed for 7-, 11-, and 15-year-old boys and girls. BMI values at the 50th percentile from Kuczmarski's smoothed percentiles (Kuczmarski et al., 2002) were used to calculate BMI values corresponding to 20 and 100% overBMI using the formula 50th percentile BMI + (50th percentile BMI × percent overBMI)/100, where percent overBMI is equal to 20 or 100%. For example, 50th percentile BMI for a 7-year-old male is 15.51, so that a BMI at 20% overBMI = 15.51 + (15.51 × 20)/100 = 18.61. BMI values corresponding to 20 and 100% overBMI provide estimates of children who are at the low and higher end of obesity.

LMS z-BMI, BMI sympercent, and percent overBMI were calculated for initial BMI values and for BMI changes of +1.0, −1.0, and −2.0 at 1-year follow-up. These BMI changes represent reasonable possibilities for children receiving weight control treatment over a 1-year period.

The differences between changes over 1 year for each of the three relative BMI measures that correspond to gaining 1.0 BMI units and losing 2.0 BMI units, and ratio of these changes were calculated for all gender, age, and initial BMI combinations. The ratio of these changes for children who were less overweight (initial 20% overBMI) versus those who were more overweight (initial 100% overBMI) were calculated by dividing the difference scores. For example, a 7-year-old girl who was 20% overBMI would show a percent overBMI value of 23.49 if they increased their BMI by 1.0 unit, or percent overBMI of 4.53 if they reduced their BMI by 2 units for a difference of 18.96 (23.49 – 4.53 = 18.96). Similarly, if that 7-year-old girl was 100% overBMI, she would have percent overBMI values of 101.60 and 82.64 for changes of 1.0 and −2.0 BMI units respectively, for a difference of 18.96 (101.60 – 82.64 = 18.96). The ratio of change for the same BMI changes for the less and more overweight youth is 18.96/18.96 = 1.

Results and discussion

Figure 1 shows changes in percent overBMI, BMI sympercent, and LMS method z-BMI for hypothetical male (left graphs) and female (right graphs) subjects over each 1-year epoch. The top two graphs in Figure 1 show that the magnitude of change in percent overBMI units are similar for both high and low initial baseline values, and consistent across the age and genders presented. For example, the differences in change magnitude for 7-, 11-, and 15-year-old boys were 19.09, 16.84, and 14.59, with the same amount of change for more or less overweight youth. All values are presented in Table 1.

Changes in BMI sympercent in the center graphs show larger differentiation of the three BMI changes in lower initial BMI individuals as opposed to high initial BMI subjects. For example, sympercent overBMI of less overweight boys showed changes that were 1.69 times as great as more overweight boys at 7 years old (16.60 vs. 9.84), 1.68 times as great at 11 years old (14.92 vs. 8.86) and 1.68 times as great at 15 years old (12.88 vs. 7.65). Sympercent overBMI changes for less overweight girls were 1.69, 1.69, and 1.68 times as great at 7, 11, and 15 years of age than for more overweight girls.

The trend of having greater relative LMS method z-BMI changes for the lower initial value cases compared to greater initial value subjects is displayed in the bottom of Figure 1. LMS method z-BMI changes for more overweight boys were 9.01 times greater than less

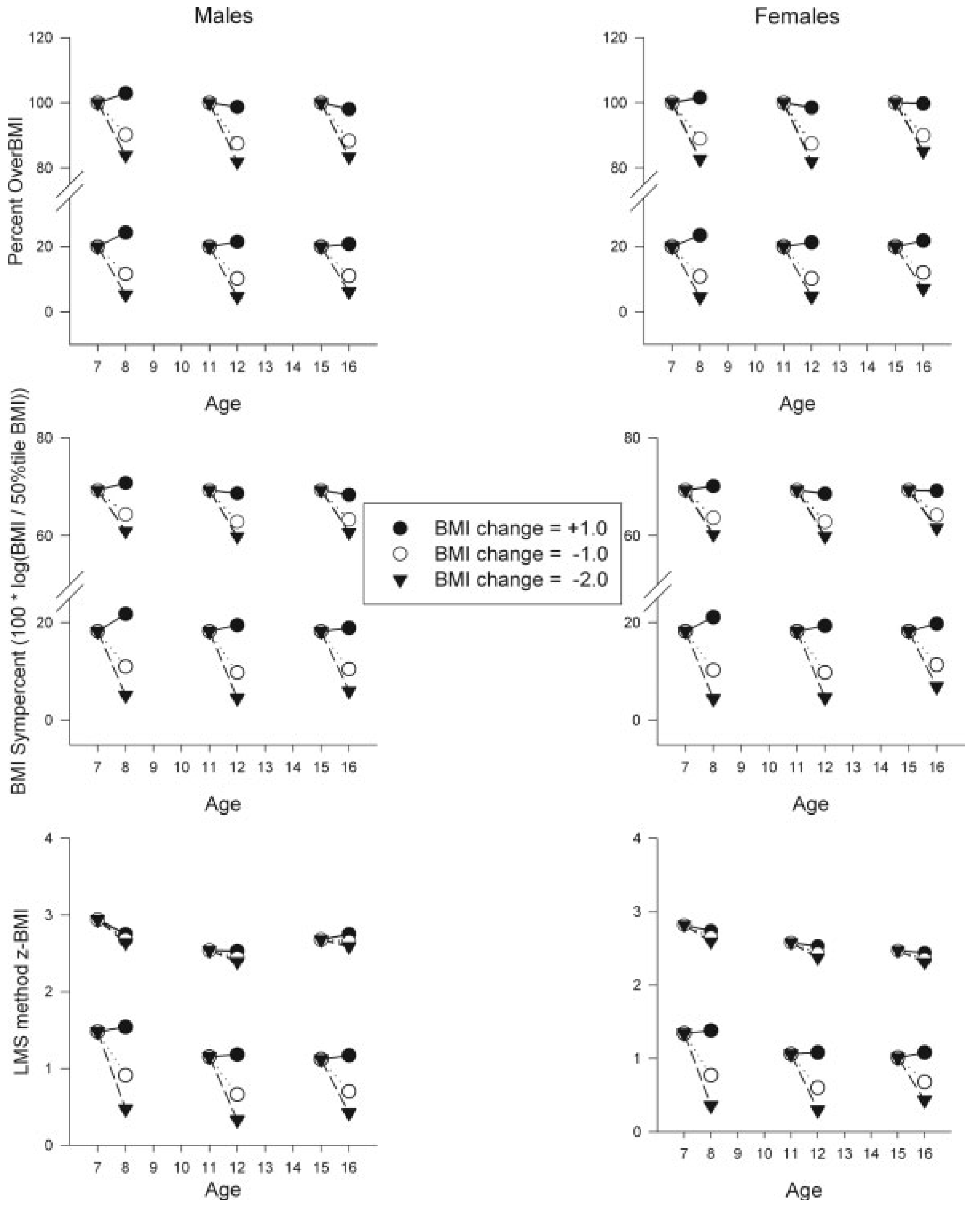

Fig. 1. Values for percent overBMI, BMI sympercent, and LMS method z-BMI corresponding to BMI changes of $+1.0$, -1.0, and -2.0 in males and females over a 1-year epoch from 7 to 8, 10 to 11, and 15 to 16 years of age for two levels of initial overweight status.

overweight boys at 7 years old (1.07 vs. 0.12), 6.08 times greater at 11 years old (0.85 vs. 0.14) and 4.88 times greater at 15 years old (0.75 vs. 0.15). Less overweight girls showed 6.67, 4.72, and 5.09 times the changes in LMS z-BMI values than more overweight girls based on LMS z-BMI.

These data show that there is an attenuation in change for heavier children who show the same degree of BMI change when LMS z-BMI measures are used. There is also an attenuation of the magnitude of change when BMI sympercent measures are used. The degree of attenuation comparing heavier versus

TABLE 1. The differences between the changes for each of the three relative BMI values comparing youth who showed an increase of 1.0 BMI units versus a decrease of –2.0 BMI units over 12 months for youth who were more or less overweight at ages 7, 11, and 15

	Percent overBMI difference			BMI sympercent difference			LMS z-BMI difference		
Age	Initial 100% overBMI	Initial 20% overBMI	Ratio	Initial 100% overBMI	Initial 20% overBMI	Ratio	Initial 100 % overBMI	Initial 20% overBMI	Ratio
Males									
7	19.01	19.01	1.00	9.84	16.60	1.69	0.12	1.07	9.01
11	16.84	16.84	1.00	8.96	14.92	1.69	0.14	0.85	6.08
15	14.59	14.59	1.00	7.65	12.88	1.68	0.15	0.75	4.88
Females									
7	18.96	18.96	1.00	9.87	16.67	1.69	0.15	1.03	6.67
11	16.57	16.57	1.00	8.72	14.69	1.69	0.17	0.78	4.72
15	14.67	14.67	1.00	7.63	12.83	1.68	0.13	0.65	5.09

Note: The for initial 100 percent overBMI or for initial 100 percent overBMI values represent the absolute differences between gaining 1.0 BMI units versus losing 2.0 BMI units. The ratio represents difference for initial 20 percent overBMI / difference initial 100 percent overBMI.

lighter children was less for BMI sympercent than LMS z-BMI. There was no attenuation of the magnitude of change for heavier versus lighter children when percent overBMI was used as the dependent measure.

COMPARISON 2

Method

LMS method z-BMI, BMI sympercent and percent overBMI were compared at 0, 6, and 12 months for 140 overweight 8–12-year-old children using data collected from two pediatric obesity studies at the University at Buffalo (Epstein et al., 2000a, b). Six subjects failed to attend the 1-year follow up leaving $N = 134$ for analyses at 1 year. Participants were from two studies that differed in their goals and study hypotheses. In Study 1, Epstein and colleagues (Epstein et al., 2000a) randomly assigned overweight youth and their parents ($N = 80$) to one of four groups that varied the targeted behaviors (sedentary behaviors vs. physical activity), and treatment dose (low vs. high). Low and high doses for the decrease sedentary or increase physical activity groups were 10 or 20 h/week of targeted sedentary behaviors, or the equivalent energy expenditure of 16.1 or 32.2 km (10 or 20 mi) per week, respectively. In Study 2, Epstein and colleagues (Epstein et al., 2000b) randomized overweight children ($N = 60$) from families to groups that received a 6-month family-based behavioral weight-control program plus parent and child problem solving, child problem solving, or standard treatment with no additional problem solving.

The common component of treatment in data from the weight control programs consisted of the Traffic Light diet (Epstein et al., 2000a) and a physical activity program. The Traffic Light diet is a color-coded food exchange system that categorizes foods based on macro- and micronutrient content. Green foods are low in fat and high in nutrient density, and are encouraged to be increased. Yellow foods have between 2 and 5 g of fat per serving, and moderate nutrient density, and should be eaten in moderation. Red foods have 5 or more grams of fat per serving, or have very high content of simple sugars, and low nutrient density, and are taught to be decreased. Families were also taught how to rearrange their environments to support eating-related behavior change, either by making unhealthy choices more difficult to engage in or by making healthy choices more accessible. Examples included teaching families to limit the amount of red foods in the house and to increase the number of green food choices. Each study followed the participants over a 2-year period, although only data up to the 1-year assessment is presented in this analysis.

Analytic plan

Mean and standard deviations for LMS z-BMI, BMI sympercent and percent overBMI were calculated and Cohen's effect size D was calculated for each of the three measures of relative BMI at both 6 months and 1 year.

Within child variability for each measure of relative BMI was quantified using the standard deviation from the three measurements (baseline, 6 months, and 1 year), and initial levels of each relative BMI measurement were then related to within-subject variability of

TABLE 2. Characteristics of children at baseline and after 6 and 12 months of treatment (mean ± s.d.)

Months	Baseline	6 months	0–6 changes	1 year	0–1 changes
Sex (male/female)	54/86			53/81	
Age (years)	10.38 (1.17)				
Height (cm)	146.48 (8.09)	149.58 (8.11)	3.10 (1.15)	152.16 (8.22)	5.56 (1.74)
Weight (kg)	59.90 (11.26)	53.9 (11.07)	−6.03 (3.93)	58.48 (12.56)	−1.43 (6.12)
Body Mass Index (kg/m^2)	27.69 (3.08)	23.87 (3.26)	−3.82 (1.69)	25.06 (3.89)	−2.60 (2.48)
LMS method BMI z-score	2.16 (0.27)	1.59 (0.46)	−0.56 (0.29)	1.65 (0.55)	−0.50 (0.43)
BMI sympercent	48.18 (10.10)	31.23 (12.02)	−16.96 (6.97)	34.10 (14.51)	−14.04 (10.14)
Percent OverBMI	62.72 (16.42)	37.64 (16.65)	−25.08 (9.95)	42.09 (20.31)	−20.55 (13.94)

each respective measure with Pearson product-moment correlations.

Additional correlations among the relative BMI measures at each time point were calculated to establish the cross-sectional relationship between measures, as well as the relationship between baseline and change scores for each measure. Statistical differences testing the correlation between baseline and change for each relative BMI measure were tested for significance by using the Fischer r-to-Z transformed Pearson-Filon statistic for correlated but nonoverlapping correlations (Raghunathan et al., 1996). Relative BMI variables are correlated because they are from the same children, but the variables in each correlation differ from the variables in the contrasted correlation and therefore do not overlap. Linear regression analyses were done to calculate beta coefficients and the corresponding 95% confidence intervals.

Results and discussion

Characteristics of the 140 youth in the treatment database are presented in Table 2. Children were 10.4 ± 1.2 years of age, 146.5 ± 8.1 cm, 59.9 ± 11.3 kg, with a BMI of 27.7 ± 3.1, an LMS z-BMI of 2.2 ± 0.3, BMI sympercent of 3.6 ± 1.1, and percent overBMI of 48.2 ± 10.1, and 61.4% of the sample was female. Over 6 months the average youth increased their height by 3.1 ± 1.2 cm and reduced their weight by −6.0 ± 3.9 kg. This resulted in a decrease in LMS z-BMI of −0.6 ± 0.3, BMI sympercent of −17.0 ± 7.0, and percent overBMI of −25.1 ± 10.0, while 12-month changes were 5.6 ± 1.7 cm of growth, reduction in weight of −1.4 ± 6.1 kg resulting in a decrease in LMS z-BMI of −0.5 ± 0.4, BMI sympercent of −14.0 ± 10.1, and percent overBMI of −20.6 ± 13.9. Effect sizes for the three measures were similar, with ES^d of 1.52, 1.53, and 1.51 at 6 months and ES^d of 1.11, 1.12, and 1.19 at 12 months for percent overBMI, BMI sympercent and LMS method z-BMI, respectively.

Initial LMS z-BMI values were inversely correlated with within subject variability ($r = -0.31$, $P < 0.01$), indicating that as initial values increased variability decreased. Initial values of percent overBMI were positively correlated with within subject variability ($r = 0.22$, $P < 0.02$), indicating that as initial values increased variability also increased. Initial value of BMI sympercent was not significantly correlated with within subject variability ($r = -0.006$). These results are consistent with those of Cole in younger children (Cole et al., 2005).

Cross-sectional correlations between the measures at baseline, 6, and 12 months were significant for each measure (rs > 0.92, Ps < 0.0001), as were correlations of change from baseline to six (rs > 0.72, Ps < 0.0001) and 12 (rs > 0.85, Ps < 0.0001) between the measures.

Comparisons of the correlation coefficients tested with Fischer's r-to-Z transformed Pearson-Filon statistic (ZPF) showed significant differences ($P < 0.0001$) between percent overBMI models (β coefficient (confidence interval) = −0.17 (−0.27 to −0.07), $r = -0.280$, $r^2 = 0.078$, $P < 0.002$) and LMS z-BMI ($\beta = +0.34$ (0.17 to 0.52), $r = 0.380$, $r^2 = 0.096$, $P < 0.001$) or BMI sympercent ($\beta = -0.03$ (−0.15 to −0.09), $r = -0.042$, $r^2 = 0.002$, $P = 0.64$) at 6 months. Similar difference between the relationship between percent overBMI and change ($\beta = -0.09$ (−0.24 to 0.05), $r = -0.110$, $r^2 = 0.012$, $P = 0.20$) was observed at 12 months in comparison to the relationship shown for LMS z-BMI ($\beta = +0.40$, $r = 0.245$, $r^2 = 0.06$, $P < 0.001$) and BMI sympercent ($\beta = +0.03$ (−0.14 to −0.21), $r = 0.033$, $r^2 = 0.001$, $P = 0.70$).

To provide a frame of reference for the law of initial values (Wilder, 1967), we also correlated baseline weight and weight change for the children in the studies, as well as their parents. Correlations between initial child weight and weight changes showed significant negative correlations at 6 months ($r = -0.22$, $P < 0.01$). Similarly, correlations between initial parent weight and weight changes showed significant negative correlations at 6 months ($r = -0.64$, $P < 0.05$. As expected, greater initial weight was associated with greater decreases over time.

GENERAL DISCUSSION

Consistent with the analysis of Cole and colleagues (Cole, 2000), this paper illustrates differences in measures of relative BMI when assessing pediatric obesity treatment. Comparison 1 shows that the magnitude of change is attenuated for both the LMS z-BMI and BMI sympercent values for heavier versus lighter youth, with the effect more pronounced for LMS z-BMI values.

Comparison 2, which compares the three measures using data from children who participated in weight control studies, shows the attenuation of within-subject variability as BMI increases with LMS z-BMI consistent with Cole (Cole et al., 2005). It is interesting that there were no differences in effect size between measures. This must be due to proportional reductions in LMS z-BMI variability of the sample as the magnitude of the LMS z-BMI change is reduced.

The only measure that shows a negative relationship between initial level of relative BMI and relative BMI change is percent overBMI, with positive relationships shown for LMS z-BMI and no relationship shown for BMI sympercent. Thus, among the three measures studied, only percent overBMI was equally sensitive to changes in BMI throughout the full range of overweight values, and sensitive to the negative correlation between initial value and the difference score.

The similarity of effect sizes in the current set of comparisons is based on comparing treatment results for the same sample on three measures. The results obtained suggest that the three measures will be associated with relatively equivalent interpretation of change if treatments are being compared.

While the three measures produce similar effect sizes, relative BMI measures that vary in initial values differ for interpretation of individual cases. As shown in Figure 1, the magnitude of change is severely attenuated when initial BMI is large. LMS method z-BMI change scores for individuals of different initial values are not comparable to each other. The attenuation is less severe in sympercent overBMI, and not attenuated at all in percent overBMI. We recommend using percent overBMI in clinical decision making to provide participants, parents, physicians, or therapists feedback on changes in BMI over time in pediatric obesity treatments.

Relative BMI values are proxy measures for adiposity (Dietz and Robinson, 1998). BMI values are more strongly related to DEXA measured fat and fat-free mass for children above the 85th BMI percentiles than for children with lower BMI values (Freedman et al., 2004), increasing confidence for using relative BMI to assess adiposity in youth who are at risk for overweight or overweight.

In summary, LMS method z-BMI remains a valuable tool to assess overweight classifications. However, the three measures have different properties. When the measures were compared for the same sample of children who had been in a weight control study no differences in effect sizes were observed, but only percent overBMI showed that the heavier children had larger relative BMI changes. This favors percent overBMI for studies that are evaluating predictors of change, and include baseline values as a predictor.

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